Thermal Soak Analysis of SPRITE (Small Probe Reentry Investigation for TPS Engineering) Probe

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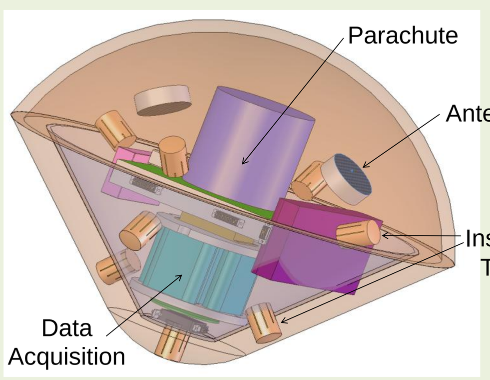
International Planetary Probe Workshop 2011 (IPPW-8) Portsmouth, VA 6-10 June2011

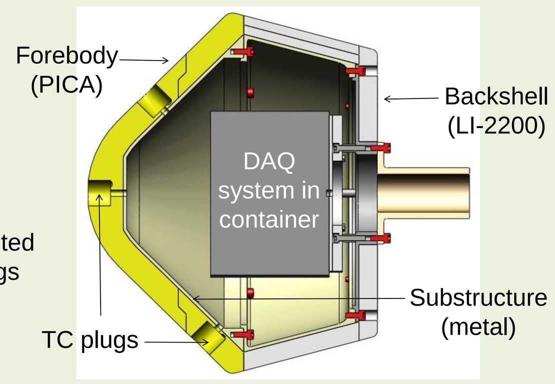
Introduction to SPRITE

Small Probe Re-entry Investigation for TPS Engineering

- Demonstrate feasibility of *test what you fly* paradigm
- *In situ* measurements of temperature, strain and recession using on-board data acquisition system
- Demonstrate the predictive capability of a combination of modeling and simulation tools – *DPLR*, *FIAT*, and *MARC*



SPRITE Concept



SPRITE Arc-jet model

1

Background

Goal: *develop correlations to predict payload temperature history for any given probe design*

- Transfer of thermal energy from a payload's heated exterior to interior can last minutes to hours
- Research under NASA's MMEEV program analyzes thermal soak of the internal payload after re-entry for any given probe design and trajectory
- Of particular interest is the internal payload's rise in temperature to determine survivability
- Finite element models (FEM) models were developed to predict temperatures of the SPRITE probe and its interior during the cool-down period
- SPRITE arc-jet tests serve as a good validation tool to test the predictive capability of thermal FEMs

SPRITE model in arc jet

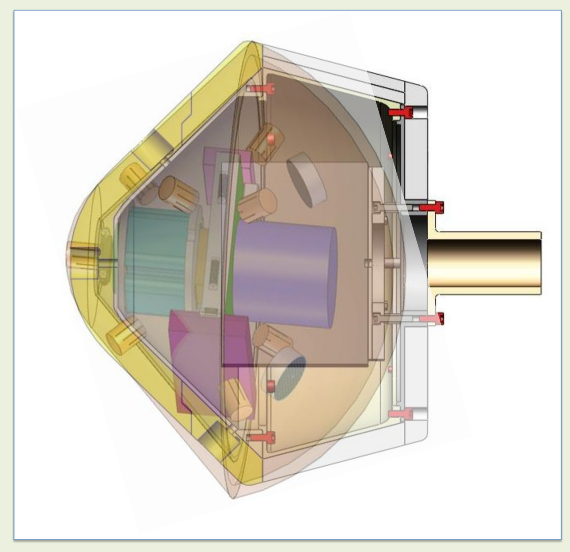
SPRITE model, post-test

2

Analysis Objectives

Objective: *improve design / material selection for substructure, container*

- Provide estimate for exposure time for optimized design
- Predict peak temperature
- Provide temperature time histories
  - bondline thermocouples
  - DAQ board
  - batteries
  - metal substructure
  - container box
- Compare analysis predictions with measured data and DAQ board
- Verify / validate predictive capability of finite element (FE) analysis tools

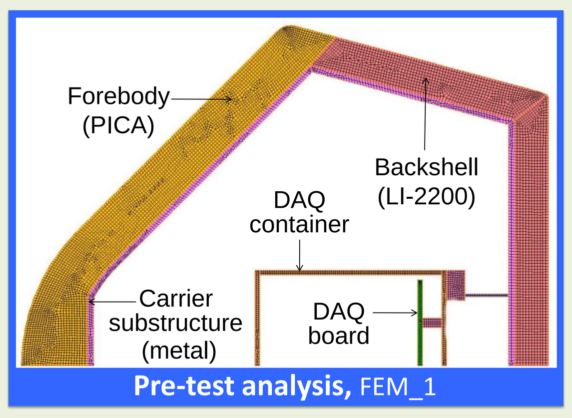


SPRITE Testing Concept

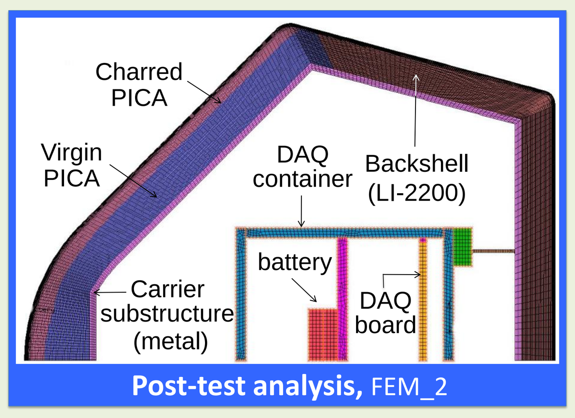
3

Analytical Approach and Model Development

2D axi-symmetric FEMs with nonlinear transient thermal analysis (MARC)



Pre-test analysis, FEM_1



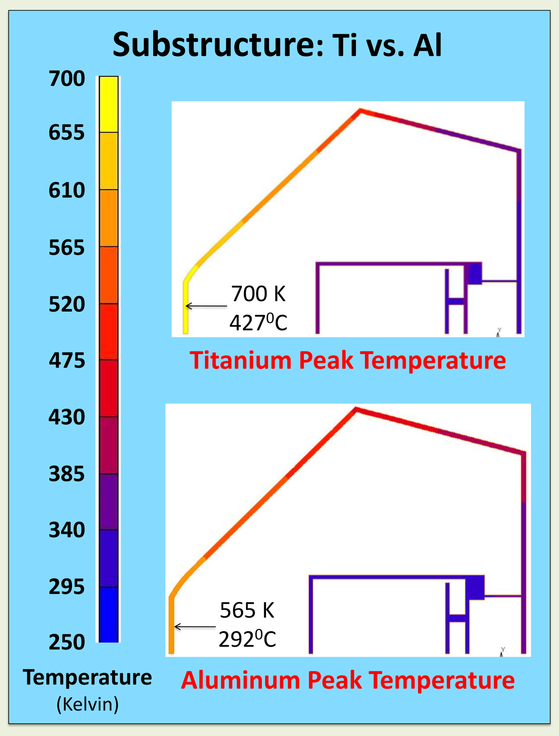
Post-test analysis, FEM_2

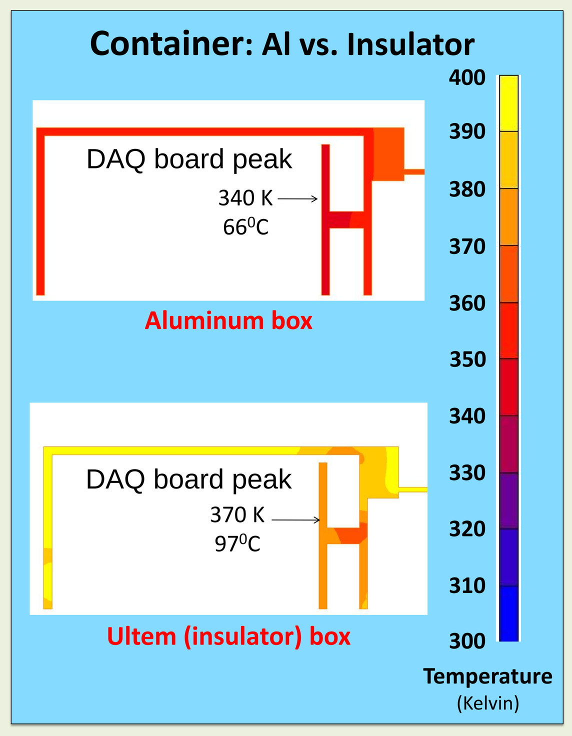
- Parametric studies for material selection, exposure time and TC locations
- Conduction re-radiation based analysis
- Conservative estimates: no pyrolysis, ablation
- Heat flux distribution from DPLR, directly imposed as boundary condition
- Battery power imposed on DAQ board

- High fidelity thermal soak post test analysis
  - Temperature and grid points from 2D FIAT (TITAN), mapped onto FE model
  - Ablation during exposure included
  - Virgin and Char PICA modeled separately
- Batteries and other components inside the metal container are included

4

Pre-test Analysis: Material Selection





Based on peak temperature, aluminum selected for substructure and container

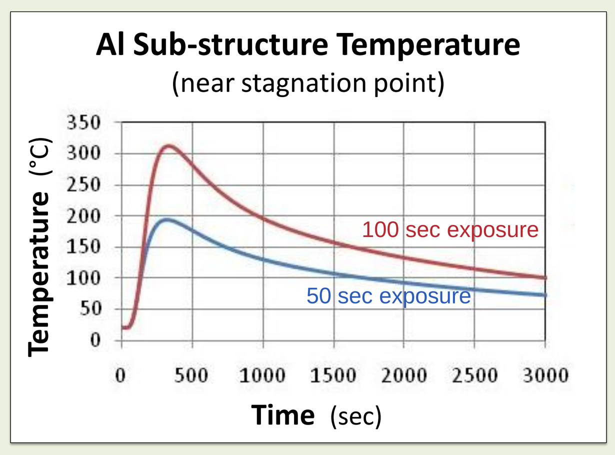
5

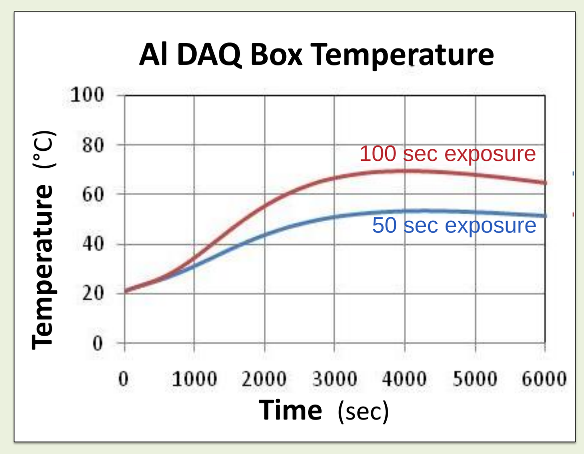
Pre-test Analysis: Exposure Time Determination

Temperature Constraints Driving Design		
Component	Temperature Constraint	Risk
Battery	60 °C	explosion
DAQ board	60 °C	electronic failure
Al Sub-structure	200 °C	thermal stress failure due to CTE mismatch

Exposure time of 50 sec selected, based on temperature histories

Peak temp in Al box and DAQ board achieved ~ 1 hour after exposure





6

Arc-jet Testing

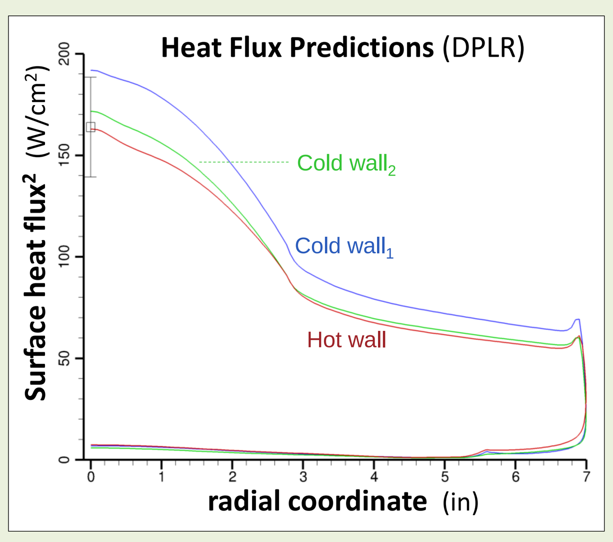
2 SPRITE models successfully arc-jet tested. Probes, DAQ system survived 50 sec exposure.

Test 1: vacuum maintained during entire cool-down
Test 2: model vented to atmosphere after some time

Conducted in the Ames AHF Arc-jet (18 in nozzle)
- Arc current: 2000 A; mass flow rate[1]: 388 g/s
- Test article, calorimeters 12 in from nozzle exit plane

SPRITE model during arc-jet test

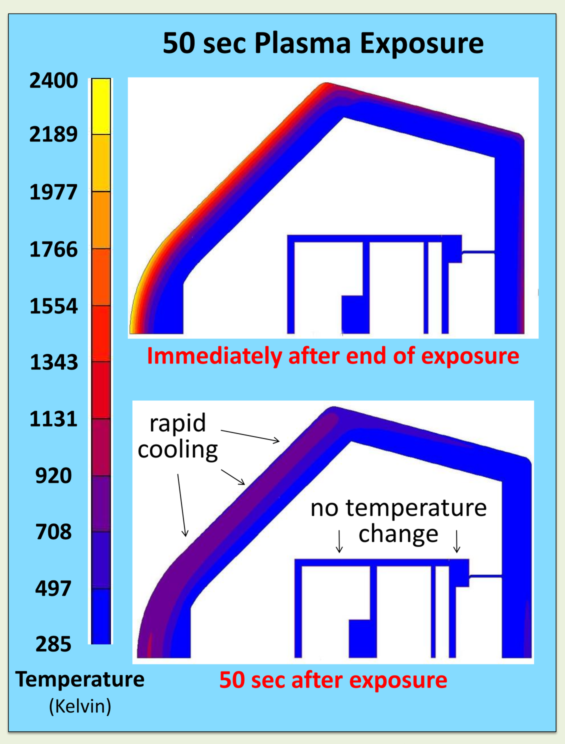
SPRITE model after arc-jet test

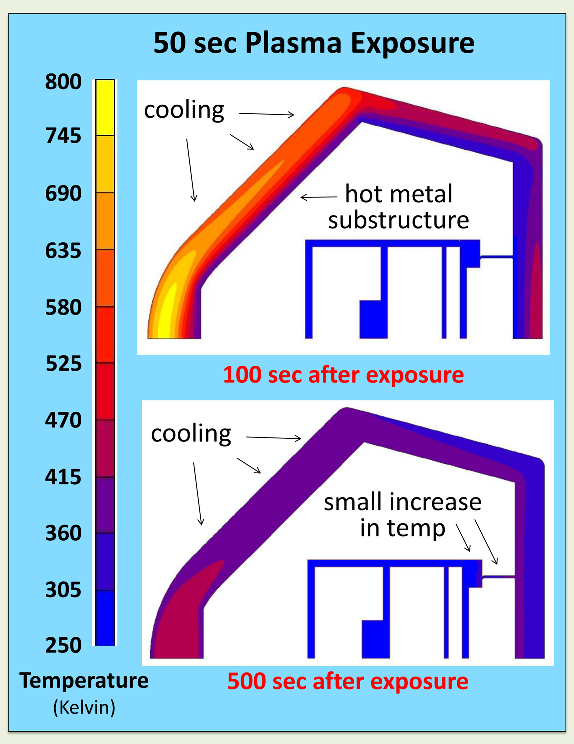


[1] includes Argon [2] fully catalytic wall

7

Thermal Soak After Exposure: Temperature contours





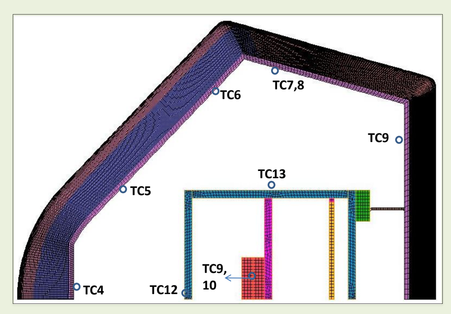
Forebody cools down rapidly after exposure
Substructure hot after 100 sec of exposure

Battery and internal components show rise in temperature only after several minutes

8

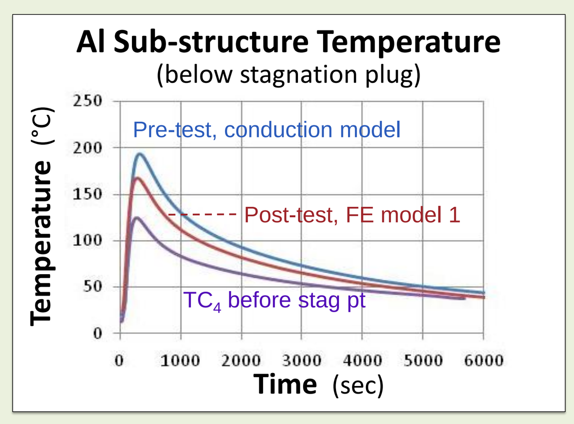
Temperature History for Al Substructure

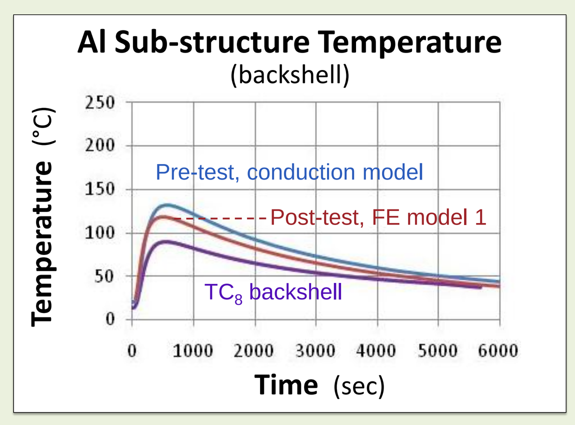
Modeling predictions and comparison with test data



Finite element predictions show same trend but higher peak temperatures compared to measured thermocouple data

Modeling predictions are conservative since ablation and pyrolysis of PICA after exposure is not accounted for

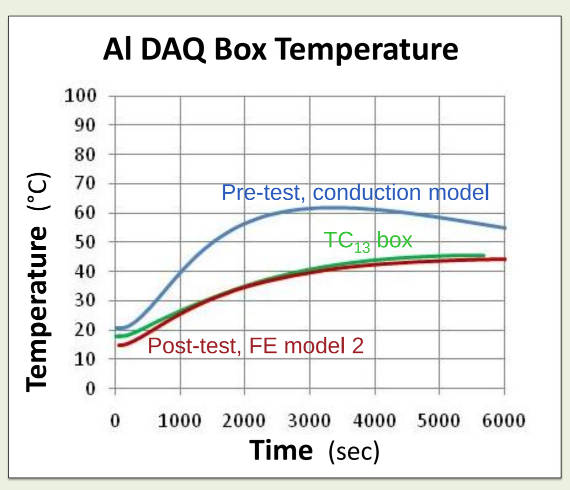


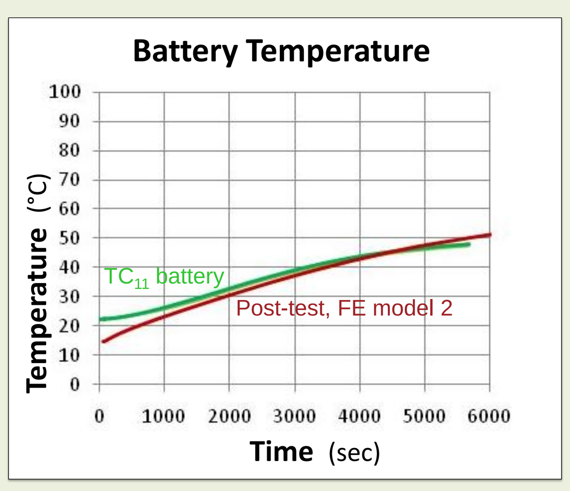


9

Temperature History for Al DAQ Box and Battery

Modeling predictions and comparison with test data





Higher fidelity post-test FE analysis predictions for aluminum DAQ container box and battery agree well with experimental results

10

Summary: Thermal Analysis of SPRITE

- Pre-test analysis provided a good insight for design optimizations
  - material selection
  - exposure time
  - thermocouple locations

  and was instrumental in conducting successful arc-jet tests
- Temperature predictions for metal electronics container box and batteries agreed well with experimentally observed data
- Demonstrated FE thermal analysis can accurately model thermal energy absorption and payload temperatures for small entry probes

Future Work

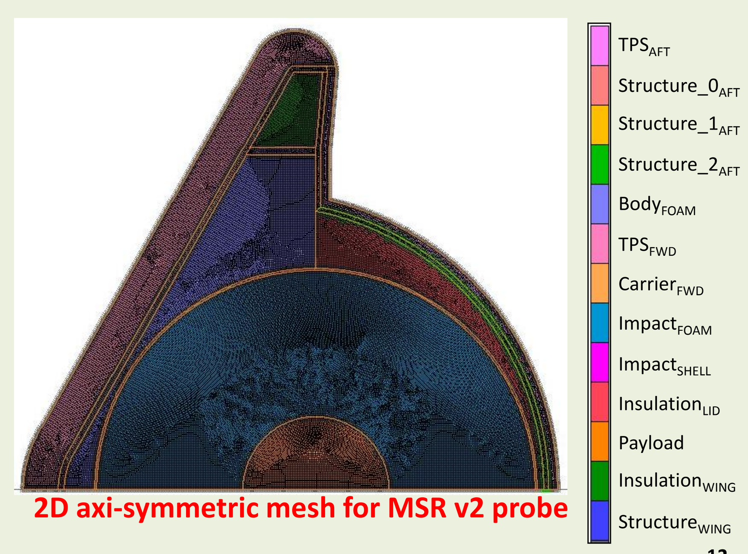
- *Investigate and isolate heat generation from battery operation*
- *Model thermal soak based on low enthalpy heat flux predictions*
- *Model vacuum release and venting to ambient air*

11

Thermal Soak Analysis of Small Probes

Recommended Work Forward

- Approach established for thermal analysis of SPRITE probe could be extended to multi-mission earth entry vehicle (MMEEV) analysis tool
- Modeling of cool-down period based on temperature maps at the end of heat-pulse from FIAT can be conducted. Temperature plots and history will be provided for the entire probe (including the payload if required)
- Based on temperature distribution it will provide thickness recommendation for sub-structure and guide in designing insulation for payload
- After a number of analyses are conducted for various trajectories, geometries and materials, the work can progress to develop correlation coefficients
- Advantage – A 2D axi-symmetric analysis over the entire geometry, providing more precise information compared to a 1D analysis over stagnation point, resulting in significant mass saving



2D axi-symmetric mesh for MSR v2 probe

12

Acknowledgement: SPRITE Team

1. ERC Inc. 2. Sierra Lobos